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3.3 W injection heterolaser based on self-organized quantum dots

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Presently there is a strong interest to semiconductor self-organized quantum dots [1]. The delta-like density of states as a function of energy is expected to provide a very high differential gain above the transparency leading to significant reductions in threshold current in appropriately designed lasers compared with their bulk and quantum well counterparts [2]. Up to now the significant progress in this field is achieved. Ground state lasing is realised in various material systems with the lowest values of threshold current density of 63 A/cm^2 [3] and 11 A/cm^2 [4] at room and liquid nitrogen temperatures, respectively.

At the beginning of investigation of QDs the possibility to achieve a high output power in QD laser diodes has not been studied in detail. In 1997 we have reported on room temperature continuous wave lasing with the output power of the order of 1 W in laser based on InGaAs/AlGaAs QDs [5]. Improving the design of the QD active region proposed in [6] allowed us to increase this value up to 1.5 W. In this work we report on the QD laser demonstrating maximum output power 3.3 W.

One of the dominant mechanisms limiting power of semiconductor laser is spectral hole burning [7], associated with the finite capture time of charge carriers on the active states. Since the capture time in InGaAs QDs is relatively large (30–40 ps [8]) and the QDs themselves are characterized by a certain number of states determined by their areal density, the perspective of using the QD lasers for high-power applications was unclear. The number of QD states can be increased by stacking the QD sheets [9] or using the vicinal surfaces for the QD formation [10]. In [6] we have proposed the alternative way to increase the areal density of QDs. The basic idea of the method is to use denser InAlAs QDs as the centres for stimulated formation of InGaAs QDs. Finally, the array of composite vertically coupled QDs is formed. The areal density is set by the InAlAs islands, whereas the optical transition energy is determined by the InGaAs QDs. Following this method we have formed the active region of the laser studied in the present work. The structure was grown by solid source molecular beam epitaxy (MBE) in Riber 32 apparatus on n$^+$-GaAs(100) substrate in standard GRIN SCH design. The scheme of the structure under investigation and the cross-section of the active region are shown in Fig. 1. The active region was inserted into the middle of the 0.5 μm $Al_{0.15}Ga_{0.85}As$ waveguide. It consisted of the array of composite vertically-coupled InAlAs/InGaAs QDs. First three QD layers were formed by successive deposition of 5.3 monolayers of InAlAs and after that three rows of InGaAs QDs were grown. 5 nm layers of $Al_{0.15}Ga_{0.85}As$ separated the QD rows. QD formation was monitored in situ by the characteristic transition of the high electron energy diffraction (HEED) pattern. The substrate temperature was 485, 700, and 600 °C during the growth of the active region, cladding layers, and waveguide, respectively. The whole structure was grown under MBE standard As-rich conditions. Broad area laser diodes (stripe width 100 μm) were fabricated. No coating was deposited on facets.

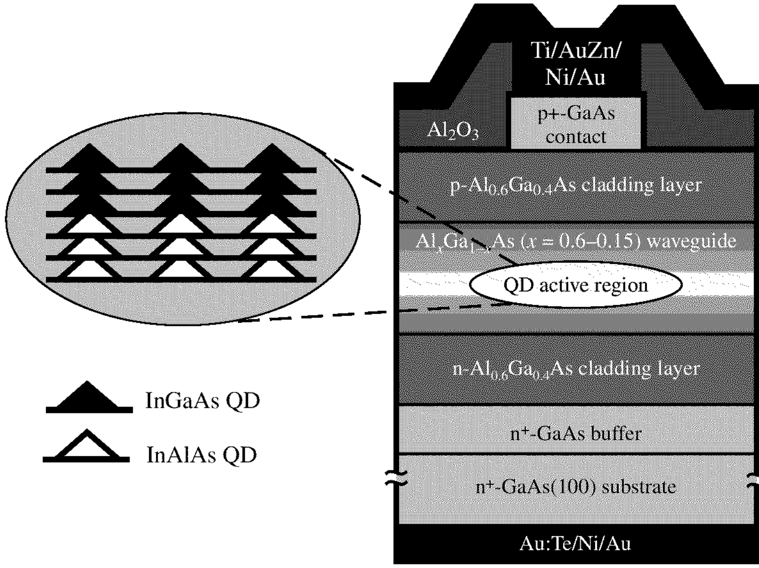

Fig. 1. The scheme of the laser based on composite vertically-coupled InAlAs/InGaAs QDs in AlGaAs matrix.

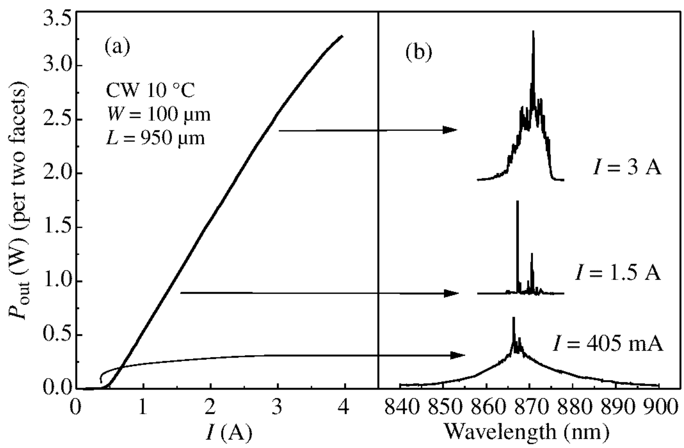

Fig. 2. (a) Light output power (P_{out}) dependence on continuous wave (CW) drive current per both facets at heat sink temperature of 10 °C; (b) lasing spectra recorded at corresponding current.

Continuous wave (CW) light output power (P_{out}) per both facets as a function of the drive current is presented in Fig. 2(a). The heat sink temperature was 10°C. The lasing spectra taken at several values of drive current are shown in Fig. 2(b). The threshold current ($I_t h$) was 402 mA, that corresponds to the current density of 423 A/cm^2. The 405 mA spectrum was recorded just above the threshold. Stimulated emission arises at the maximum of spontaneous emission, thus, one can conclude that lasing proceeds via the QD ground states. $P_{out}-I$ dependence becomes sublinear from 2.7 A due to the heating of the active region. One can see that the laser demonstrates the maximum output power as high as 3.28 W. The differential efficiency was estimated to be 73%.

Increasing the QD areal density allowed us to increase the maximum current flowing through the structure, since this current is limited by the finite amount of QDs themselves and relatively slow capture of carriers into them. Moreover, this leads to the decrease in population of the wetting layer and matrix states at the same pumping level, that in its turn, results in the reduction of parasitic current and structure overheating caused by recombination via upper states. Both these facts are very important to achieve high output power.

Thus, in this work we demonstrated room temperature CW lasing via the QD states with the maximum output power as high as 3.3 W. This result points out that QDs can be used as an active region of injection lasers for high-power applications. We believe that further progress can be achieved by optimizing both the design of active region and the fabrication of laser diodes.

Acknowledgements

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